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# Modeling the Impact of Conservation Tillage Practices on Pesticide Concentrations in Ground and Surface Waters

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For ground water, only four pesticides demonstrated mean annual loadings high enough to require estimation of resulting ground water concentrations. These four also had the highest surface water loadings and are characterized by $K_{oc}$ values of 100 ml $g^{-1}$ or less and root zone half-lives of 35 d or longer.

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# MODELING THE IMPACT OF CONSERVATION TILLAGE PRACTICES ON PESTICIDE CONCENTRATIONS IN GROUND AND SURFACE WATERS

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**Abstract**—To analyze the environmental fate and migration of pesticides applied to croplands as they are affected by conservation tillage practices, pesticide models for leaching, surface water and ground water were selected and an application method was developed. Fourteen different pesticides applied to corn and soybeans were analyzed to determine probable concentrations in ground water and surface water under conventional tillage, reduced tillage and no tillage practices; the Lake Erie Basin was the study site. Surface runoff loadings and concentrations decreased under the conservation tillage scenarios, but ground water loadings and concentrations increased as a result of the decreased runoff and increased ground water recharge. Reduced tillage decreased surface runoff loads and concentrations by about 50% as compared with conventional tillage, and no tillage resulted in another 20% reduction. The pesticides with the highest surface runoff loads and concentrations were those with $K_{oc}$ values generally less than 200 ml $g^{-1}$ and root zone half-lives greater than 40 d.

For ground water, only four pesticides demonstrated mean annual loadings high enough to require estimation of resulting ground water concentrations. These four compounds also had the highest surface water loadings and are characterized by $K_{oc}$ values of 100 ml $g^{-1}$ or less and root zone half-lives of 35 d or longer.

Ground water concentrations for all four compounds were low, with carbofuran showing the highest concentrations (approaching 1.0 ppb). Next was dicamba, but its concentrations were four to five orders of magnitude less. Sensitivity analyses for carbofuran indicated that the concentrations could be at least one order of magnitude higher, depending on assumptions related to decay rate, hydraulic conductivity and other hydrogeologic parameters.

**Keywords**—Pesticides Modeling Tillage practices Ground water Surface water

## INTRODUCTION

Conservation tillage is promoted as a means of reducing agricultural chemical runoff and soil erosion and of providing savings in energy and labor. Conservation tillage also can promote better soil structure (for soil moisture retention and crop growth) and decrease farm overhead by reducing the operating time of large, costly farm vehicles [1,2].

Conservation tillage leaves a protective crop residue on the soil surface after harvest. This cover promotes more efficient water management by increasing the amount of water that filters through the soil. The amount of water entering the soil profile and leaving the plant root zone is the upper bound of ground water recharge. (Water can be intercepted by tile drains or impermeable layers above the water table.) Soluble pesticides may be carried with recharging water and contaminate ground water; they also can be carried with runoff and eroded sediment to contaminate surface waters.

Agricultural and tillage practices vary widely among different regions and within a single region because of differences in local climate, soils, topography and crops. The selection of a specific tillage practice or strategy is based on many factors, such as production costs, pesticide and fertilizer use, expected pest problems, crop rotation

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practices and available machinery [3]. The tillage methods available cover a broad spectrum but generally have been grouped in terms of conservation versus conventional practices [1]. They also have been classified as no-till, reduced-till and conventional-till [3]. The differences among the systems are related to the degree of soil disturbance and the amount of plant residue left on the soil surface.

The protective cover provided by crop residue on the land surface and the less frequent and less severe soil disturbances associated with conservation tillage have complex effects on soil hydrology, sediment erosion and chemical processes. The ability to analyze the effects of various agricultural management practices requires a detailed definition of the practice, an understanding of how the practice affects soil processes and a method for integrating the effects of many different factors related to climates, soils, pesticides and crops. Mathematical models frequently are used to evaluate the response of agricultural fields and their water resources to various land management practices, climatic conditions, chemical factors and cropping techniques. The use of models is a logical, meaningful mechanism for evaluating the effects on ground and surface water quality of plant-soil management practices and chemical processes and reactions.

Evaluating the effects on ground and surface water quality of different land management practices and pesticide use requires the selection of a model (or models) from which these effects can be translated to specific, quantitative changes in model parameters. In addition, various pesticide properties are required to fully understand the effects of land management practices on pesticide transport and transformation. Three models, including the Pesticide Root Zone Model (PRZM) [4], the Analytical Transient One-, Two- and Three-Dimensional Simulation of Waste Transport in the Aquifer System (AT123D) [5] and the Steam Transport and Agricultural Runoff of Pesticides for Exposure Assessment: A Methodology (STREAM) [6], were operated to evaluate pesticide concentrations in ground water and surface water [7]. PRZM, an unsaturated zone model, was used to develop edge-of-field loadings of selected pesticides for both the saturated zone model AT123D and the surface water module of STREAM.

This article describes the application of this integrated modeling method to evaluate the effects of conventional-, reduced- and no-till land management practices for corn and soybeans on ground and surface water pesticide concentrations in the Lake Erie Basin (eastern corn belt).

## MODEL LINKAGE

The linkage between PRZM and the component models AT123D and STREAM involves analysis and transformation of the ground and surface water loadings generated from the unsaturated zone simulations with PRZM. These analyses are necessary because of the differences in the models and methods used and the differences in time steps for pesticide residence in each medium.

PRZM is a fully dynamic, numerical model that can provide daily time series of pesticide loadings for surface runoff and ground water; AD123D is an analytical model that assumes steady, uniform flow. STREAM is not a computer model; it is a set of graphical procedures (based on computer model simulations) for estimating the frequency and duration of pesticide concentrations and the frequency of pesticide runoff for various agricultural crops and regions across the United States. Because of these differences, five conditions had to be evaluated: the size of the source area, the depth to ground water, the rate of pesticide application, the timing of loadings to ground water and the interface between PRZM and STREAM.

A standard source area was selected that corresponded to the mean farm size (121.5 ha) in the Lake Erie Basin (J. Haigh, personal communication). Because shallow, unconfined aquifer systems appear most susceptible to pesticide contamination [8], a range of depth to shallow ground water from 150 to 900 cm was identified [9]. A total unsaturated zone depth of 230 cm (i.e., the depth to the ground water surface) was estimated that corresponded to the mean of high water levels in 30 observations [9].

To evaluate the impact of variation in the depth to ground water, a sensitivity analysis was conducted to determine whether a shallower depth would affect the loadings simulated by PRZM. The results indicated that a depth shallower than 230 cm would not significantly affect PRZM predictions. Thus, the selected depth to ground water would represent the most likely condition (in terms of distance the pesticide must travel) for expected ground water concentrations. To more fully evaluate the effect of land management practices and pesticide characteristics, a unit rate of application to the soil surface of 1.0 kg $ha^{-1}$ was simulated.

The loadings to ground water (and input to AT123D) were simulated by a long-term simula-

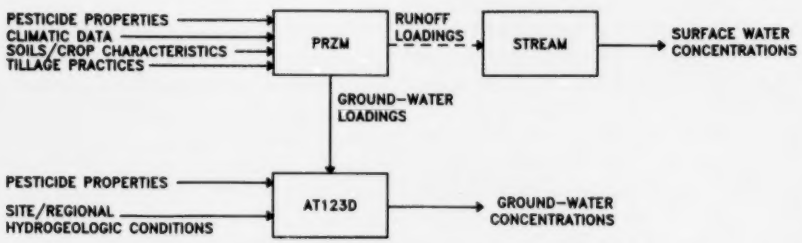


Fig. 1. Model linkage method for conservation tillage impact assessment.

tion with PRZM (29 years) and aggregating the results into monthly and yearly values. The mean and maximum values and the monthly time periods in which the loadings occurred were obtained. A seasonal fluctuation of ground water loadings was identified that corresponded with periods of high ground water recharge from November to May. Thus, the mean annual load could be distributed over those seven months. These procedures allow a reasonable representation of the time variable loading to ground water to be maintained.

The operation of PRZM with STREAM is not a linkage between computer codes because STREAM is not a computer model. STREAM is an entirely independent procedure for estimating surface runoff and resulting in-stream concentrations. STREAM was developed under the assumption of conventional tillage and therefore could not be used to evaluate the effects of different practices. PRZM was used to estimate the runoff loadings for the various tillage practices, and then the in-stream component of STREAM was used to evaluate the pesticide concentrations that resulted from the predicted loadings.

A schematic of the models selected and their linkage for use in evaluating the effects of conservation tillage practices on pesticide concentrations in ground water and surface water are shown in Figure 1.

## HYDROLOGY

The Lake Erie Basin (Fig. 2) was selected for evaluation because of the intensive agriculture and

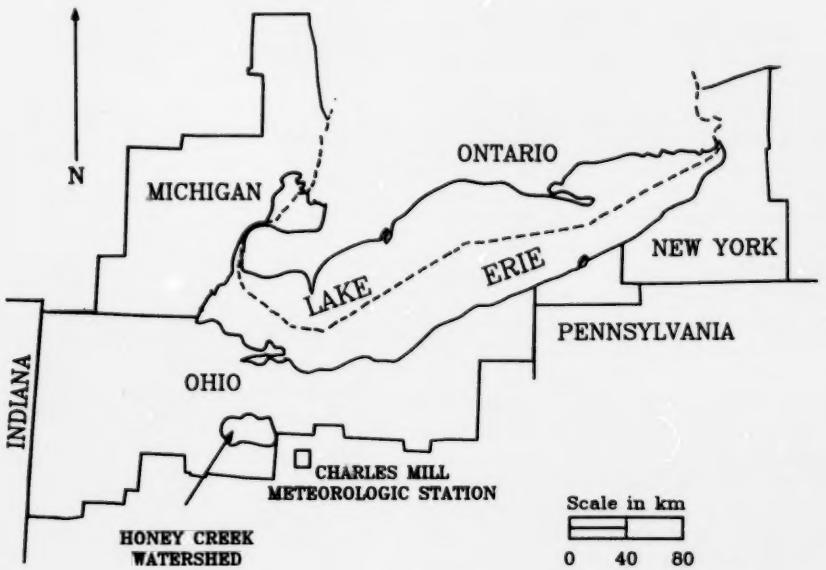


Fig. 2. Map of Lake Erie Basin.

extensive pesticide use there, the availability of hydrologic data for model calibration and the fact that the area was included in the STREAM methodology [6,10,11]. Land in the Lake Erie Basin is relatively level; 75% is used for growing crops, primarily corn and soybeans [11]. The soils consist of fine to medium textured clays and loams derived from the glacial till deposits that represent approximately 96% of the land area [11].

The initial parameterization of PRZM for the Lake Erie Basin was developed from regional soils and topographic and hydrologic data from field evaluations [6,10] conducted within the Honey Creek watershed. A calibration exercise [6,12] was conducted with PRZM to establish a representative hydrologic response for the basin. Calibration is required for parameters that have not been deterministically evaluated within the region. Parameters used in the calibration exercise included pan evaporation factor (evapotranspiration), drainage rate (runoff and recharge) and storm duration (erosion). After calibration, a comparison of observed yearly runoff from the Honey Creek watershed for the years 1976 to 1978 was conducted. Actual runoff [11] for the Honey Creek watershed for 1976, 1977 and 1978 was 17, 29 and 29 cm, respectively; PRZM-predicted runoff was 21, 30 and 34 cm, respectively. Annual average erosion for the Honey Creek watershed is 7.7 mt $ha^{-1}$ [11]; predicted annual average erosion was 7.8 mt $ha^{-1}$. The annual water and sediment balance simulated with PRZM after calibration was representative of that of the Lake Erie Basin. Estimated hydrological characteristics of the Lake Erie Basin are provided in Table 1.

The simulated conventional-, reduced- and no-till practices were selected to cover the full range of farming techniques commonly used. Conventional-till is specifically defined to include primary and secondary tillage for seedbed preparation, usually with a moldboard plow or multiple disking, resulting in complete loss or burial of crop residue. Reduced-till includes practices that disrupt the entire land surface but to a lesser extent than in conventional tillage, with a minimum of 30% residue remaining. This definition encompasses both mulch-till and reduced-till. No-till is defined as a practice that leaves the soil surface undisturbed until planting. Planting is completed in a narrow seedbed 3 to 9 cm wide. No-till, ridge-till and strip-till are encompassed by this definition. These broad definitions of tillage practices provide a realistic basis for estimating parameter changes for PRZM based on the limited information available.

The PRZM parameters selected to represent the implementation of conservation tillage were the Soil Conservation Service curve number, the soil field capacity ($cm^3/cm^3$), the soil organic carbon content (percent) and the Universal Soil Loss Equation (USLE) cropping factor. These parameters were selected to reflect tillage-practice impacts on soil hydrology, sediment erosion and chemical processes. Hydrological effects generally include increased soil moisture, reduced evaporation and increased infiltration leading to reduced runoff. The reduced runoff also generally results in less erosion by overland flow, and the residue cover reduces the amount of fine sediment material generated by raindrop splash for transport by overland flow. Crop residues on the land surface may influence sorption and other pesticide processes by increasing the organic carbon content of the surface soil.

A 10% reduction in Soil Conservation Service curve number for crop residues associated with no-till was estimated using a method [13,14] based on crop residue and tillage effects for describing the runoff/infiltration differences between conven-

Table 1. Hydrologic characteristics (average values) of the Lake Erie Basin

| Characteristic | Hydrology | Soils | Ground water |
|---|---|---|---|
| Precipitation (cm) | 82.0 | | |
| Runoff (cm) | 16.0 | | |
| Erosion (mt $ha^{-1}$) | 7.7 | | |
| Recharge (cm) | 13.0 | | |
| Soil type | | Blount silt loam | |
| Field capacity ($cm^3/cm^3$) | | 0.330 | |
| Wilting point ($cm^3/cm^3$) | | 0.133 | |
| Bulk density ($gm^3/cm^3$) | | | |
| Soil surface | | 1.3 | |
| Plant root zone | | 1.5 | |
| Subsoil | | 1.6 | |
| Organic carbon fraction | | | |
| Soil surface | | 0.15 | |
| Plant root zone | | 0.005 | |
| Subsoil | | 0.001 | |
| Hydraulic conductivity (m $h^{-1}$) | | | 0.0025 |
| Hydraulic gradient | | | 0.004 |
| Effective porosity | | | 0.25 |
| Dispersivity (m) | | | |
| Longitudinal | | | 10.0 |
| Vertical | | | 1.0 |
| Lateral | | | 1.0 |
| Source area (ha) | | | 121.5 |

Data for refs. 4, 6, 9-11.

Table 2. PRZM parameter changes for conventional-till (CT), reduced-till (RT) and no-till (NT)

| Parameter | Crop | Crop stage | CT | RT | NT |
|---|---|---|---|---|---|
| CN | Corn | Fallow | 88 | | |
| | | Cropping | 82 | 75 | 74 |
| | | Residue | 88 | 78 | 77 |
| | Soybeans | Fallow | 88 | | |
| | | Cropping | 82 | 76 | 74 |
| | | Residue | 88 | 79 | 77 |
| ISCOND | | | Fallow | Residue | Residue |
| ICNAH | | | Fallow | Residue | Residue |
| USLEC | Corn | Fallow | 0.78 | 0.22 | 0.12 |
| | | Cropping | 0.38 | 0.16 | 0.10 |
| | | Residue | 0.71 | 0.24 | 0.17 |
| | Soybeans | Fallow | 0.64 | 0.42 | 0.22 |
| | | Cropping | 0.40 | 0.28 | 0.15 |
| | | Residue | 0.48 | 0.41 | 0.33 |
| THEFC | Horizon 1 | | 0.33 | 0.35 | 0.37 |
| OC | Horizon 1 | | 0.015 | 0.020 | 0.025 |

Data from refs. 13–19. CN, curve number; ISCOND, initial surface condition; ICNAH, surface condition after harvest; USLEC, Universal Soil Loss Equation cropping factor; THEFC, volumetric water content ($cm^3/cm^3$); OC, organic carbon fraction.

tional and no-till for corn and soybeans in the Lake Erie Basin. For reduced-till, 7 and 8% reductions for corn and soybeans, respectively, were estimated using this method. Changes in the USLE cropping factor were based on the USLE manual guidelines [15].

Changes in organic carbon were based on limited data [16,17] that indicated an approximate doubling of organic matter and organic carbon in the soil surface layers as a result of crop residue left after no-till practices. A 67% increase for the surface layer in the Lake Erie Basin for no-till was assumed because the soil surface layer in these studies was deeper than the 10-cm depth reported for the area [18; D. Jeffers, personal communication]. The increased organic carbon was determined using a linear correlation between depth and organic carbon. An intermediate value was determined for reduced-till. These changes in organic carbon were used to evaluate any increases in the soil field capacity [19]. This method assumes that an increase in organic carbon of 1% leads to a 0.04 $cm^3/cm^3$ increase in field capacity for no-till. An intermediate value of 0.02 $cm^3/cm^3$ was assumed for reduced-till. Estimated hydrologic parameter changes for reduced-till and no-till are given in Table 2.

## PESTICIDE CHARACTERISTICS

Simulating the transport and transformation of pesticides in soils and in ground and surface waters requires that chemical/soil interactions be evaluated to define sorption and decay (or attenuation) characteristics. To demonstrate the effect that different land management practices have on pesticide concentrations in ground and surface waters, a wide range of pesticide characteristics must be evaluated. The major pesticides used in the Lake Erie Basin under different tillage practices are presented in Table 3 (J. Haigh, personal communication).

The three soil horizons [20] simulated for the Lake Erie Basin were the surface horizon (10 cm), the plant root zone (60 and 90 cm for soybeans and corn, respectively) and the remaining depth to the water table (170 and 140 cm for soybeans and corn, respectively). The organic carbon and bulk density values for each horizon were obtained from available sources [18].

The organic carbon distribution coefficient ($K_{oc}$) can be used for estimating the partition coefficient of pesticides for soil and water [21]. $K_{oc}$ can be estimated from the octanol-water partition coefficient or the water solubility [21]. The specific sorption partition coefficients (e.g., $K_d$) for selected pesticides in individual soil horizons for the Lake Erie Basin were obtained by multiplying measured or estimated $K_{oc}$ values [22–25] (P.S.C. Rao, personal communication) by the organic carbon fraction in each soil horizon. The $K_d$ values determined for selected pesticides are given in Table 4. The $K_{oc}$ and $K_d$ values estimated

Table 3. Analysis of pesticide/tillage practice combinations

| | Conventional-till | Reduced-till | No-till |
|---|---|---|---|
| Corn | | | |
| Herbicides | | | |
| Atrazine | X | X | X |
| Alachlor | X | X | X |
| 2,4-D amine | X | X | X |
| Butylate | X | X | *b* |
| Dicamba | X | X | *c* |
| Metolachlor | X | X | X |
| Insecticides | | | |
| Fonofos | X | X | X |
| Carbofuran | X | X | X |
| Soybeans | | | |
| Herbicides | | | |
| Alachlor | X | X | X |
| Linuron | X | X | X |
| Metribuzin | X | X | X |
| Trifluralin | X | X | X |
| Bentazon | *d* | X | X |
| Metolachlor | X | X | X |
| Insecticides | | | |
| Carbaryl | X | X | X |
| Toxaphene | X | X | X |

From John Haigh (personal communication). *b*, *c* and *d* indicate pesticides not typically used for these tillage practices.

for the selected pesticides cover a wide range of potential sorption characteristics.

The transformation rate of the pesticides for the unsaturated zone, saturated zone and the suspended and bed sediment compartments of the surface water in-stream channel are needed to estimate the mass (kg $ha^{-1}$) loadings to ground and surface waters and subsequent concentrations. Transformation rates of the selected pesticides for the plant root zone were determined from reported values [4,23,26–28] for each compound or other similar pesticides in order to select an appropriate rate for each pesticide. Transformation rates ($K_s$) for selected pesticides are given in Table 5.

Available data on transformation rates of pesticides in subsurface soil horizons and ground water are limited. Studies conducted for atrazine and aldicarb [29–31] using surface and subsurface soils indicated a 0.3 to 0.5 reduction of the transformation rate. The transformation of pesticides in soil is related to the soil's characteristics such as pH, temperature, moisture and oxidation/reduction potential. Similar factors are important for transformation in ground water. Based on limited laboratory data, transformation rates in the horizon below the plant root zone and in ground water were assumed to be 50% of the rate in the surface soil.

There are few data available on the effects that conservation tillage practices may have on pesticide transformation. When tillage is reduced, an increase in soil moisture and therefore pesticide degradation would be expected; however, acidification at the soil surface is increased and soil covered by stubble is warmed less [32]. Several studies that evaluated the effect of straw mulch on the degradation of atrazine and oryzalin in soil did

Table 4. Calculated $K_d$ for the surface soil horizon for different tillage practices

| | | Horizon $K_d$ (ml $g^{-1}$) | | | | |
|---|---|---|---|---|---|---|
| | | CT[a] | | | RT[a] | NT[a] |
| Pesticide | $K_{oc}$ (ml $g^{-1}$) | 1 | 2 | 3 | 1 | 1 |
| Alachlor | 342.0 | 5.13 | 1.71 | 0.34 | 6.84 | 8.55 |
| Linuron | 841.0 | 12.62 | 4.20 | 0.84 | 16.82 | 21.02 |
| Metribuzin | 95.0 | 1.42 | 0.48 | 0.10 | 1.90 | 2.38 |
| Trifluralin | 13700.0 | 206.00 | 68.50 | 13.70 | 274.00 | 342.00 |
| Bentazon | 264.00 | 3.96 | 1.32 | 0.26 | 5.28 | 6.60 |
| Atrazine | 172.0 | 2.58 | 0.86 | 0.17 | 3.44 | 4.30 |
| 2,4-D amine | 109.1 | 1.64 | 0.55 | 0.11 | 2.18 | 2.73 |
| Butylate | 12200. | 183.00 | 61.00 | 12.20 | 244.00 | 305.00 |
| Dicamba | 2.2 | 0.03 | 0.01 | 0.002 | 0.04 | 0.055 |
| Metolachlor | 100.0 | 1.50 | 0.50 | 0.10 | 2.00 | 2.50 |
| Carbaryl | 229.0 | 3.44 | 1.14 | 0.23 | 4.58 | 5.72 |
| Toxaphene | 1389.0 | 20.84 | 6.94 | 1.39 | 27.78 | 34.72 |
| Fonofos | 846.0 | 12.69 | 4.23 | 0.85 | 16.92 | 21.15 |
| Carbofuran | 29.0 | 0.44 | 0.14 | 0.03 | 0.58 | 0.72 |

Data from refs. 21–25. CT, conventional-till; RT, reduced-till; NT, no-till.
[a]Numbers 1, 2, 3 refer to soil horizons in PRZM. Values estimated for conventional-till were used for reduced- and no-till for soil horizons 2 and 3.

Table 5. Plant root zone degradation rates ($K_s$)

| | $K_s$ (per day) |
|---|---|
| Alachlor | 0.0400 |
| Linuron | 0.0173 |
| Metribuzin | 0.0132 |
| Trifluralin | 0.0320 |
| Bentazon | 0.0256 |
| Atrazine | 0.0149 |
| 2,4-D amine | 0.0231 |
| Butylate | 0.0385 |
| Dicamba | 0.0197 |
| Metolachlor | 0.0170 |
| Carbaryl | 0.0578 |
| Toxaphene | 0.0014 |
| Fonofos | 0.0158 |
| Carbofuran | 0.0099 |

Data from refs. 24, 26–28.

not find any difference between mulched and unmulched soils [32,33]. Consequently, the first-order degradation rates for selected pesticides were not modified for simulations of reduced- and no-till practices.

The solution pesticide transformation rate is required by STREAM for estimating in-stream concentrations of the edge-of-field loadings predicted by PRZM. The transformation rate has little impact on in-stream pesticide concentrations unless the associated half-life is comparable to the mean flow-through time of 3 to 5 d for the Lake Erie Basin watershed [6]. If the compound half-life is significantly longer than the flow-through time, the pesticides will not decay appreciably. Because pesticide loading to the stream will occur primarily during high-flow periods associated with runoff events, the actual time during which transformation can occur will be significantly less than the mean flow-through time [6]. Because of the controlling influence of the flow-through time, the solution decay rate was set equal to 0.05 $d^{-1}$ (i.e., the lowest rate used in STREAM) for all pesticides except 2,4-D amine (0.15 $d^{-1}$), carbaryl (0.40 $d^{-1}$), and carbofuran (0.096 $d^{-1}$) [34]. The $K_{oc}$ and $K_s$ values were those used for the plant root zone.

## RESULTS AND DISCUSSION

Surface water concentrations for the pesticides evaluated, using a 1.0 kg $ha^{-1}$ application rate, calculated as the mean, 5% exceedance and 1% exceedance for conventional-, reduced- and no-till

Table 6. Dissolved pesticide concentrations in surface water predicted by STREAM for a 1.0 kg $ha^{-1}$ application (unit solution concentrations; ppb)

| | Conventional-till | | | Reduced-till | | | No-till | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1% exceedance[a] | 5% exceedance[a] | Mean | 1% exceedance | 5% exceedance | Mean | 1% exceedance | 5% exceedance | Mean |
| Corn | | | | | | | | | |
| Alachlor | 55.0 | 23.7 | 5.3 | 29.2 | 12.6 | 2.8 | 22.6 | 9.7 | 2.2 |
| Atrazine | 102.9 | 42.0 | 10.1 | 46.3 | 18.9 | 4.5 | 43.2 | 17.6 | 4.2 |
| Butylate | 5.6 | 3.4 | 0.6 | 2.7 | 1.6 | 0.3 | — | — | — |
| Carbofuran | 128.4 | 50.8 | 12.8 | 60.3 | 23.9 | 6.0 | 66.8 | 26.4 | 6.7 |
| 2,4-D amine | 100.6 | 39.4 | 9.6 | 55.3 | 21.7 | 5.3 | 45.3 | 17.7 | 4.3 |
| Dicamba | 118.6 | 45.9 | 11.4 | 74.7 | 28.9 | 7.2 | — | — | — |
| Fonofos | 36.4 | 19.8 | 3.9 | 17.1 | 9.3 | 1.8 | 12.4 | 6.7 | 1.3 |
| Metolachlor | 113.2 | 44.7 | 11.0 | 52.1 | 20.6 | 5.1 | 50.9 | 20.1 | 5.0 |
| Soybeans | | | | | | | | | |
| Alachlor | 107.3 | 33.7 | 8.0 | 52.6 | 16.5 | 3.9 | 38.6 | 12.1 | 2.9 |
| Bentazon[b] | 154.4 | 47.6 | 11.6 | 64.8 | 20.0 | 4.9 | 47.3 | 14.6 | 3.6 |
| Carbaryl | 100.4 | 25.9 | 6.8 | 44.2 | 11.4 | 3.0 | 37.1 | 9.6 | 2.5 |
| Linuron | 54.7 | 25.0 | 5.2 | 25.2 | 11.5 | 2.4 | 18.1 | 8.2 | 1.7 |
| Metribuzin | 244.1 | 71.1 | 18.1 | 126.9 | 37.0 | 9.4 | 100.1 | 29.2 | 7.4 |
| Metolachlor | 234.7 | 67.7 | 17.3 | 122.0 | 35.2 | 9.0 | 93.9 | 27.1 | 6.9 |
| Toxaphene | 86.5 | 53.7 | 11.6 | 36.3 | 22.6 | 4.9 | 25.1 | 15.6 | 3.4 |
| Trifluralin | 7.9 | 4.6 | 0.9 | 4.0 | 2.3 | 0.4 | 2.7 | 1.6 | 0.3 |

[a]Daily solution concentration exceeded 1 or 5% of the time.

[b]Bentazon was not simulated under conventional-till; reduced-till concentrations were calculated by reducing the STREAM conventional-till concentrations by the following factor: PRZM reduced-till loading/STREAM conventional-till loading = 0.42. Bentazon concentrations were calculated by multiplying the reduced-till concentrations by the ratio of the mean daily load for reduced-till to no-till, i.e., 0.73.

practices are given in Table 6. Because the concentrations are linear functions of the application rate, a 2.0 kg $ha^{-1}$ application would produce concentrations twice those shown in Table 6. The in-stream concentrations for the pesticides evaluated were reduced by the implementation of either reduced- or no-till practices. Reduced-till decreased the in-stream concentrations by approximately 50% as compared with simulated values for conventional-till. No-till reduced the concentration an additional 20%. Pesticides with $K_{oc}$ values of less than 200 ml $g^{-1}$ and root zone transformation rates of less than 0.017 $d^{-1}$ (i.e., half-life of 41 d) had the highest surface runoff concentrations. Toxaphene was the only major exception, with a higher $K_{oc}$ of 1,389 ml $g^{-1}$. The mean concentration for all pesticides evaluated was approximately one order of magnitude lower than the 1% exceedance values.

Ground water concentrations were simulated for only four pesticides, carbofuran, dicamba, metolachlor and metribuzin (Table 7). The pesticides had $K_{oc}$ values of less than 100 ml $g^{-1}$ and plant root zone transformation rates of 0.019 $d^{-1}$ or longer. Ground water concentrations for all four pesticides were low, with carbofuran having the highest concentration, of 1.0 ppb. Reduced-till increased the ground water pesticide concentration as compared with conventional-till; the extent of the increase varied with the specific pesticide. For example, carbofuran and metolachlor concentrations were increased by factors of 4 and 10, respectively.

Because uncertainty in the combined procedures for evaluating the effects of conservation tillage practices was highest for the saturated zone assessment, a sensitivity analysis was conducted to evaluate the effects of pesticide decay and hydraulic conductivity on ground water concentrations of the pesticide carbofuran. A series of simulations was performed reducing the ground water transformation rate to 0.0 $d^{-1}$ (compared with the original rate of 0.0099 $d^{-1}$) and increasing the hydraulic conductivity to 0.025 m $h^{-1}$ (compared with the original conductivity of 0.0025 m $h^{-1}$). The effects on the ground water concentrations underneath the source area and 20 m down-gradient were compared. The results (Table 8) indicate that the transformation rate has the greatest impact underneath the source area, whereas conductivity has the greatest impact down-gradient from the source. The worst case of zero transformation and higher conductivity resulted in the highest concentrations down-gradient. Because of

Table 7. Predicted maximum ground water concentrations (ppb)[a] beneath the midpoint of the source area, resulting from a 1.0 kg $ha^{-1}$ application

| | Conventional-till | | | Reduced-till | | | No-till | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | 5% exceedance | Maximum | Mean | 5% exceedance | Maximum | Mean | 5% exceedance | Maximum |
| Carbofuran | 0.038 | 0.18 | 0.22 | 0.18 | 0.53 | 0.84 | 0.18 | 0.53 | 0.81 |
| Dicamba | 1.03(E−5) | 7.27(E−5) | 1.44(E−4) | 2.19(E−5) | 1.24(E−4) | 1.50(E−4) | — | — | — |
| Metribuzin | 8.34(E−7) | 6.79(E−6) | 1.13(E−5) | 2.02(E−5) | 8.10(E−5) | 1.98(E−4) | 2.12(E−5) | 8.08(E−5) | 1.98(E−4) |
| Metolachlor (soybeans) | 1.99(E−8) | 1.68(E−8) | 3.17(E−7) | 5.94(E−7) | 2.45(E−6) | 7.53(E−6) | 6.37(E−6) | 4.09(E−6) | 7.59(E−6) |
| Metolachlor (corn) | 3.57(E−10) | 1.84(E−9) | 7.07(E−9) | 2.48(E−8) | 1.85(E−7) | 3.79(E−7) | 2.08(E−8) | 1.85(E−7) | 3.15(E−7) |

Most calculated concentrations are below expected detection limits; such values are included primarily for the purpose of comparing the tillage practices.
[a]E indicates the value of the exponent; e.g., E−5 means $10^{-5}$.

Table 8. Results of sensitivity analysis for effect of decay and hydraulic conductivity on carbofuran concentrations (ppb)[a] in ground water

| | Sensitivity analysis conditions | | Carbofuran concentration | | | |
|---|---|---|---|---|---|---|
| | | | Midpoint of source | | 20 m down-gradient of source | |
| Case | Decay ($d^{-1}$) | Hydraulic conductivity ($m\ h^{-1}$) | Mean | Maximum | Mean | Maximum |
| 1 | 0.0099 | 0.0025 | 0.038 | 0.22 | 1.07(E−8) | 6.08(E−8) |
| 2 | 0.0 | 0.0025 | 0.59 | 3.31 | 3.27(E−5) | 1.91(E−4) |
| 3 | 0.0 | 0.025 | 0.35 | 1.97 | 0.042 | 0.24 |
| 4 | 0.0099 | 0.025 | 0.093 | 0.55 | 4.06(E−4) | 2.30(E−3) |

[a]E indicates the value of the exponent; e.g., E−5 means $10^{-5}$.

the uncertainty in transformation and conductivity, the values in Table 7 should be considered an indication of the general order of magnitude of pesticide concentrations in shallow ground water.

The results simulated for implementing reduced- and no-till practices in the Lake Erie Basin indicate that for selected pesticides the in-stream concentrations from pesticide runoff would decrease and the ground water concentrations from pesticide leaching would increase. The proper selection of pesticide and land management practices could decrease the overall risk of pesticide use. Further research into the transformation of pesticides in surface and subsurface soil horizons as affected by different tillage practices and in ground water is needed. Additional research on the effect that land management practices have on model parameters should be pursued. Finally, actual field assessments are needed to more fully understand the impact of conservation tillage on ground and surface water quality.

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## REFERENCES

1. **Crosson, P.R.** 1976. Conservation tillage and conventional tillage: A comparative assessment. Soil Conservation Society, Ankeny, IA.
2. **Phillips. S.H.** and **H.M. Young.** 1973. No tillage farming. Reiman Associates, Milwaukee, WI.
3. **Duffy, M.** and **M. Hanthorne.** 1984. Returns to corn and soybean tillage practices. Agricultural Economic Report No. 508. Economic Research Service, U.S. Department of Agriculture, Washington, DC.
4. **Carsel, R.F., C.N. Smith, L.A. Mulkey, J.D. Dean** and **P.P. Jowise.** 1984. User's manual for the pesticide root zone model (PRZM): Release 1. EPA-600/3-84-109. U.S. Environmental Protection Agency, Athens, GA.
5. **Yeh, G.T.** 1981. Analytical transient one-, two-, and three-dimensional simulation of waste transport in the aquifer system. ORNL-5602. Oak Ridge National Laboratory, Oak Ridge, TN.
6. **Donigian, A.S., Jr., D.W. Meier** and **P.P. Jowise.** 1984. Stream transport and agricultural runoff of pesticides for exposure assessment: A methodology. EPA/600/3-86/011a. U.S. Environmental Protection Agency, Athens, GA.
7. **Donigian, A.S., Jr.** and **R.F. Carsel.** 1985. Impact of conservation tillage on pesticide concentrations in ground water, surface water, and air. U.S. Environmental Protection Agency Integrated Environmental Management Division, Washington, DC.
8. **Carsel, R.F.** and **C.N. Smith.** 1984. Rachael Carson's *Silent Spring* and the impact of pesticides—past and present—on ground water contamination. Presented at the American Chemical Society Symposium, "*Silent Spring* Revisited," Philadelphia, PA, August 28, 1984.
9. **McKelvey, V.E.** 1974. Groundwater levels in the United States 1968–1972: Northeastern states. Geological Survey Water Supply Paper 2140. U.S. Geological Survey, Washington, DC.
10. **Baker, D.B.** 1984. Fluvial transport and processing of sediments and nutrients in large agricultural river basins. EPA-600/83-054. U.S. Environmental Protection Agency, Athens, GA.
11. **Baker, D.B.** 1985. Regional water quality impacts of intensive row crop agriculture: A Lake Erie Basin case study. *J. Soil Water Conserv.* **40**:125–132.

12. **Donigian, A.S., J.C. Imhoff, B.R. Bicknell** and **J.L. Kittle.** 1984. Application guide for hydrologic simulation program—FORTRAN (HSPF). EPA-600/3-82-069. U.S. Environmental Protection Agency, Athens, GA.
13. **Rawls, W.J., C.A. Onstad** and **H.H. Richardson.** 1980. Residue and tillage effects on SCS runoff curve numbers. *Trans. Am. Soc. Agr. Engngs.* **12**: 357–361.
14. **Rawls, W.J.** and **H.H. Richardson.** 1983. Runoff curve numbers for conservation tillage. *J. Soil Water Conserv.* **Nov–Dec**:494–496.
15. **Wischmeier, W.H.** and **D.D. Smith.** 1978. Predicting rainfall erosion losses—A guide to conservation planning. *Agricultural Handbook No. 538.* U.S. Department of Agriculture, Washington, DC.
16. **Blevins, R.L., M.S. Smith, G.W. Thomas** and **W.W. Frye.** 1983. Influence of conservation tillage on soil properties. *J. Soil Water Conserv.* **May–June**: 301–305.
17. **Dick, W.A.** 1983. Organic carbon, nitrogen, and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. *J. Soil Sci. Soc. Am.* **47**:102–107.
18. **Rapparlie, D.F.** and **D.R. Urban.** 1973. Soil survey of Hancock County, OH. U.S. Department of Agriculture, Soil Conservation Service, Findlay, OH.
19. **Rawls, W.J., D.L. Brakiensiek** and **K.E. Saxton.** 1982. Estimation of soil water properties. *Trans. Am. Soc. Agr. Engngs.* **25**:1316–1320.
20. **Soil Conservation Service.** 1980. Soil survey of Seneca County, Ohio. U.S. Department of Agriculture, Washington, DC.
21. **Karickhoff, S.W.** 1984. Organic pollutant sorption in aquatic systems. *J. Hydraul. Eng.* **110**:707–735.
22. **Hassett, J.J., J.C. Means, W.L. Banwart** and **S.G. Wood.** 1980. Sorption properties of sediments and energy related pollutants. EPA-600/3-80-041. U.S. Environmental Protection Agency, Athens, GA.
23. **Rao, P.S.C.** and **J.M. Davidson.** 1980. Estimation of pesticide retention and transformation parameters required in nonpoint source pollution models. In M.R. Overcash and J.M. Davidson, eds., *Environmental Impact of Nopoint Source Pollution.* Ann Arbor Science Publishers, Ann Arbor, MI, pp. 23–67.
24. **Rao, P.S.C., V.E. Berkheiser** and **L.T. Ou.** 1984. Estimation of parameters for modeling the behavior of selected pesticides and orthophosphate. EPA-600/3-84-019. U.S. Environmental Protection Agency, Athens, GA.
25. **Kenaga, E.E.** and **C.A.I. Goring.** 1980. Relationship between water solubility, soil sorption, octanol-water partitioning and bioconcentration of chemical in biota. In *Proceedings of the Third Aquatic Toxicology Symposium.* STP 707. American Society for Testing and Materials, Philadelphia, PA. pp. 78–115.
26. **Stewart, B.A., D.A. Woolhiser, W.H. Wischmeier, J.H. Caro** and **M.H. Fere.** 1975. Control of water pollution from cropland. EPA/600-2-75-026a. U.S. Environmental Protection Agency, Athens, GA.
27. **Wauchope, R.D.** and **R.A. Leonard.** 1980. Maximum pesticide concentrations in agricultural runoff: A semi-empirical prediction formula. *J. Environ. Qual.* **9**:665–672.
28. **Nash, R.G.** 1980. Dissipation rate of pesticides from soils. In CREAMS, A field scale model for chemical, runoff, and erosion from agricultural management systems, Vol. 3. Conservation Research Report No. 26. U.S. Department of Agriculture, Washington, DC, pp. 560–594.
29. **Lavy, T.L., F.W. Roeth** and **C.R. Fenster.** 1973. Degradation of 2,4-D and atrazine at three soil depths in the field. *J. Environ. Qual.* **2**:132–137.
30. **Wehtje, G., L.N. Mielke, R.C. Leavitt** and **J.S. Schepers.** 1984. Leaching of atrazine in the root zone of an alluvial soil in Nebraska. *J. Environ. Qual.* **13**:507–513.
31. **Smelt, J.H., M. Leistra, N.W.H. Houx** and **A. Dekker.** 1978. Conversion of aldicarb and its oxidation products in soils. I. Aldicarb sulfone. *Pestic. Sci.* **9**:279–285.
32. **Hossein, G., P.J. Shea, G.A. Wicks** and **L.C. Haderlie.** 1984. Atrazine dissipation in conventional-till and no-till sorghum. *J. Environ. Qual.* **13**:549–552.
33. **Banks, P.A.** and **E.L. Robinson.** 1984. The fate of oryzalin applied to straw-mulched and nonmulched soils. *Weed Sci.* **30**:164–168.
34. **Dawson, G.W., C.J. English** and **S.E. Petty.** 1980. Physical-chemical properties of hazardous waste constituents. Prepared by Battelle Pacific Northwest Laboratories, Richland, WA, for U.S. Environmental Protection Agency Environmental Research Laboratory, Athens, GA.